nuclear-related air cleaning systems and components.

2.3.1.5 REDUNDANCY AND SEPARATION

The ESF systems designed to contain and mitigate design basis accidents must be redundant, and these redundant systems must be physically separated so that damage to one does not cause damage to the other.

Redundancy requires two complete trains of equipment and components. There are cases where ductwork has not been completely redundant. A common space served by the redundant trains, such as control rooms, may not require 100 percent redundancy of the ductwork as long as it can be demonstrated that no common mode failures would render both trains of equipment inoperable.

Separation is required so that postulated accidents such as internal missiles, fire, flood, and HELB cannot render both trains of the redundant system inoperable from the same event. Separation can be achieved by physically locating the trains far enough apart that postulated accidents cannot render both trains inoperable, or by erecting a physical barrier, such a concrete wall, for protection.

2.3.1.6 MATERIAL RESTRICTIONS

Most nuclear power plants restrict the amount of zinc and aluminum that can be used inside the containment structures. Zinc and aluminum both interact with the spray chemistry of the emergency core cooling systems to produce hydrogen, which can accumulate in the containment and become an explosion hazard in the event of a LOCA. The amounts of these materials must be tightly controlled, and an accurate inventory must be kept when these materials are used inside containment structures.

Since most HVAC and air cleaning systems use galvanized steel for ductwork and equipment housings, alternate materials need to be considered for use inside containment structures. One option is to use stainless steel for ductwork and equipment housings. Stainless steel is expensive, but its advantage is that it does not require any coating to prevent the corrosion or scratching that can occur during repair, maintenance, or testing/surveillance activities. In addition, it is easier to decontaminate than some other materials. Another, less costly option is to use steel and to provide a coating that is compatible with the containment environment. The disadvantage of using coated steel is that it does not hold up well to activities where the ductwork or equipment is subject to high repair, maintenance, or testing/surveillance activities. The coating also must be inspected and repaired when damaged, and this can cause critical time delays during refueling or other time-sensitive activities.

Galvanized steel ductwork can be used successfully outside containment, and at a lower cost than stainless steel. Galvanized steel has many of the same advantages as stainless steel, such as ease of decontamination, and it holds up well in areas that are subject to frequent repair, maintenance, testing, and surveillance activities. One caution should be noted, however: if the galvanized coating is damaged severely or removed, as in cases when welded duct construction is used and when supports are attached by welding, then the damaged areas must be recoated with a zinc-rich paint to prevent corrosion.

2.4 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT SYSTEMS

2.4.1 ENGINEERED SAFETY FEATURE SYSTEMS

For ESF applications, applicable regulations, codes, and standards must be combined with good engineering practice. Ease of maintenance, operability, testability, cleanability, and decontamination also must be carefully considered. In addition, air cleaning systems must be integrated into the overall plant or process design, including monitoring and control requirements. ESF Systems are supplied with assured power from the Plant Class IE emergency electrical power system.

Applicable Regulations and Standards for ESF Air Cleaning Systems

Specific regulations, regulatory guides, Standard Review Plans (SRPs), and industry guidance and consensus standards govern the design criteria and operating characteristics for ESF air cleaning systems. Although these criteria are generated specifically for commercial nuclear generating stations, the principles can be adapted to other nuclear facilities.

Regulatory guides and the SRPs provide more specific guidance and are considered acceptable ways of satisfying regulatory requirements. Regulatory Guide 1.52, "Design, Testing, and Maintenance Criteria for Post Accident Engineered-Safety-Feature Atmosphere Cleanup System Air Filtration and Adsorption Units of Light-Water Cooled Nuclear Power Plants,"[17] details criteria for operating Control Room air cleaning systems in a post-accident environment. Environmental and system design criteria, component design criteria, qualification testing, maintenance, and in-place testing are discussed in detail.

The SRPs are documents prepared by the NRC staff to indicate how the staff intends to review applications to construct and operate nuclear power plants (NUREG-0800).[39]

The following criteria are applicable to ESF systems for all applications.

- A single active failure cannot result in loss of the system functional performance capability.
- Failure of nonseismic Category I equipment or components will not affect the system operation.
- A suitable ambient temperature can be maintained for personnel and equipment.
- The system can detect and filter airborne contaminants before entering the area.
- The system can detect and isolate portions of the system in the event of fires.
- The ESF ventilation system will continue to function for all DBAs that require the building or area of the plant to be habitable and that require the essential equipment served by the ESF ventilation system to remain in operation.

2.4.2 DESIGN CONSIDERATIONS

A clear definition of the design parameters is probably the most important, but often the least appreciated, requirement leading to the development of a satisfactory air cleaning system. The design parameters must consider basic performance requirements; physical limitations; regulatory, code, and standard compliance; and accident containment and recovery. All of these parameters must be identified as an initial system design step because they form the basis for design. This is the responsibility of the facility owner, who is often assisted by an architectural engineering firm with experience in this type of plant design. See Table 2.1 for system environmental parameters.

Outdoor design conditions can be obtained from the ASHRAE Guide and Data Books,[31] from local weather stations, or from site meteorological data. It is important when selecting outside design conditions to use the *most extreme* data, particularly for nuclear-safety-related systems, as they must be capable of operating in these extremes.

Section 2.2 lists common system design requirements. These points must be carefully considered as they lead to a safe, efficient, and cost-effective system.

2.4.2.1 SYSTEM DESIGN

Individual ESF air cleaning systems are limited by Regulatory Guide 1.52[17] to approximately 30,000 cfm. When the system airflow exceeds this limit, multiple systems must be used in parallel. ESF systems contain the following sequential components: (1) a moisture separator to remove entrained water droplets, (2) a heater to control relative humidity (RH) when the RH of the air entering the carbon adsorber exceeds 70 percent, (3) prefilters, (4) HEPA filters, (5) a charcoal adsorber, (6) HEPA filters downstream of the adsorbers, and (7) a fan. Ducts, valves, and dampers are also included for system isolation and flow control, as well as related instrumentation. When the moisture and dust loads are low for all credible operating modes, the prefilter and moisture separator may not be required.

As stated previously, ESF systems designed to contain and mitigate accidents must be redundant, and the redundant systems must be physically separated so that damage to one does not cause damage to the other. Instruments must make flow rates and pressures available to the Control Room as well as locally, and must provide visual and auditory alarms as indicated in ASME AG-1, Appendix IA-C, Table IA-C.[30] All instruments, including heater, damper, and fan controls should meet the requirements of IEEE 323, "Standard for Qualifying Class 1E Electrical Equipment for Nuclear Power Generating Stations"[32] and IEEE 344, "Recommended Practice for Seismic Qualification of Class 1E Equipment in Nuclear Generating Stations."[40] Regulatory Guide 1.100, "Seismic Qualification of Electrical Equipment for Nuclear Power Plants,"[41] and Regulatory Guide 1.105, "Instrument Set Points,"[42] are also applicable. Instrument controls and control panels should meet the design, construction, installation, and testability criteria in Section IA of ASME Code AG-1.[29]

The design, construction, and test requirements of ASME Code AG-1[29] apply to the following ESF air cleaning components and are titled accordingly.

- Section AA, "Common Articles"
- Section BA, "Fans and Blowers" [Motors for fans and blowers must also meet the qualification requirements of IEEE 334,[43] IEEE 323,[32] and IEEE 344.[40]]
- Section DA, "Dampers and Louvers"
- Section SA, "Ductwork"
- Section HA, "Housings"
- Section RA, "Refrigeration Equipment"
- Section CA, "Conditioning Equipment"
- Section FA, "Moisture Separators"
- Section FB, "Medium Efficiency Filters"
- Section FC, "HEPA Filters"
- Section FD, "Type II Adsorber Cells"
- Section FE, "Type III Adsorber Cells"
- Section FF, "Adsorbent Media"
- Section FG, "Frames"
- Section FH, "Other Adsorbers"
- Section FI, "Metal Media Filters"
- Section FJ, "Low-Efficiency Filters"
- Section FK, "Special Round and Duct Connected HEPA Filters"
- Section IA, "Instrumentation and Controls"
- Section TA, "Field Testing of Air Treatment

2.4.2.2 STRUCTURAL AND SEISMIC DESIGN

The structural design of ESF air cleaning systems must consider the service conditions that components and their housing may experience during normal, abnormal, and the accident conditions contained in Article AA-4000 of ASME AG-1.[30] The ESF air cleaning system must remain functional following dynamic loading events such as an earthquake. The ESF air cleaning systems, including all components, must have their structural design verified by analysis, testing, or a combination of both. Qualification criteria are contained in Article AA-4000 of ASME AG-1.[30] The design requirements for determining housing plate thickness and stiffener spacing and size are contained in ASME-AG-1, Article AA-4400, "Structural Design," Sections SA, "Ductwork," and HA, "Housings." [30]

The maximum allowable deflections for panels, flanges, and stiffeners for the load combinations of Table 5.2 are contained in ASME AG-1, Section SA-4230, "Deflection Criteria."[30]

2.4.2.3 EQUIPMENT QUALIFICATION

The fundamental reason for qualifying equipment is to provide adequate levels of safety for the life of the facility. Equipment qualification assures the ESF system will satisfy three characteristics:

- The equipment will resist common mode failures due to aging degradation.
- Nonmetallic materials will survive anticipated environmental stresses.
- The equipment and its mountings will withstand the seismic forces generated during anticipated earthquakes.

Generic or Application-Specific Qualification

Qualification may be generic or application-specific. Generic qualification is probably best applied by the original equipment manufacturer. This type of qualification program requires test parameters that may exceed the needs of the specified requirements to be able to use the qualified equipment in a variety of applications and environments. An application-specific qualification limits the use of the component or system to those with the same or lesser environmental parameters.

Mild or Harsh Environment Qualification

A mild environment qualification can usually be accomplished without determination of a qualified lifetime (per Section 4 of IEEE 323),[31] whereas a harsh environment program usually requires testing to verify performance under extreme accident conditions. Simulated aging is necessary to arrive at "end of life conditions" prior to accident condition testing.

The design criteria in Section 2.2 are important in determining a mild or harsh environment (in addition to complete design criteria).

Determining Mild or Harsh Environment

When the answers to *all* of the questions below[29] are "Yes", the equipment should be assumed to be subjected to a mild environment and treated accordingly. Otherwise, it should be treated under the assumption that it is subjected to a harsh environment.

- Will the environment where the equipment is located be unaffected during and after a DBA (i.e., will there be no significant changes in temperature, radiation)?
- Will the equipment perform its safety-related function *before* the environment becomes harsh?
- Will failure of the equipment in a harsh environment after it has performed its function:
  - result in misleading information?
  - affect the functioning of other safety-related equipment?
  - cause a breach of pressure boundary integrity?

Safety or Non-Safety-Related Function

It is necessary to determine whether the components are designated as safety-related or non-safety-related. Non-safety-related items can often be excluded from the qualification process when it can be shown that failure of that component would have no adverse effect on the safety function of the overall equipment.

Equipment Qualification Plan

The qualification plan must be developed in accordance with IEEE 323.[32] It must include a determination of the qualification method, a listing of the environmental service conditions, a description of any required aging programs, a protocol of the test sequence, and a definition of the accident test profiles.

An aging program consists of all stress factors, including thermal aging, mechanical/cyclic aging, radiation exposure, and mechanical vibration. All are designed to simulate the conditions that would be encountered during the expected life of the test specimen prior to their undergoing an accident condition or test such as seismic pressure, HELB, or LOCA.

Equipment Qualification Methods

Three equipment qualification methods are described below.

- Type Testing:
  - accounts for significant aging mechanisms;
  - subjects the equipment to specified service conditions; and
  - demonstrates subsequent ability to perform safety function.
- Operating Experience:
  - must be compared to equipment with the same generic design; and
  - depends on documentation of past service conditions, equipment performance, maintenance, and similarity for its validity.

- Analysis:
  - requires logical assessment or mathematical model of the equipment;
  - requires the support of test data, operating experience, or the physical laws of nature; and
  - must be documented to permit verification by a competent third party.

A combination of any of the above qualification methods is recommended.

2.4.2.4 AIR CLEANING SYSTEM INTEGRATION WITH THE ENTIRE FACILITY

A critical design consideration that is often overlooked is the question of how the air cleaning system interrelates with other air handling systems and the entire facility. Often areas of a facility are directly connected to more than one air handling system. There are an unlimited number of possible combinations, but some of the most common are:

- An ESF air cleaning unit exhausting an area supplied by a non-safety HVAC system
- An ESF air cleaning unit in an area normally exhausted by a large fan that may or may not shut down when the safety system is activated
- A Control Room ESF air cleaning unit designed to provide a positive pressure in an area served by other ESF and/or non-ESF systems
- The maintenance of graduated levels of negative pressure in concentric rings in fuel plants or plutonium facilities
- Gloveboxes, hot cells, and laboratory hoods with independent filtration systems in rooms served by ESF or non-ESF systems

These examples illustrate the need to consider the entire facility when designing an ESF system. Two questions must be addressed: (1) how can the system under design affect other systems and areas? and (2) how can the remainder of the facility affect this system?

2.4.2.5 DESIGN AREAS REQUIRING SPECIAL ATTENTION

There are system characteristics that apply to all air cleaning systems regardless of their specific function or the nature of the facility. One is that they must be capable of continuing to meet quantifiable test criteria to provide evidence of maintaining acceptance limits over the life of the installation. *Therefore, the ability to maintain and test systems is as important as the ability of the systems to meet the initial performance criteria*. The following are sample of some of the factors that apply to all systems and must be addressed.

- Air flow distribution in the ducts and housings
- Air flow balance through the inlet and/or outlet ducts
- Fan balance, leaktightness, and a capacity to provide adequate pressures at all design flows
- Access for inspection, maintenance, and replacement
- Instrumentation that integrates the overall control and monitoring requirements of the facility

2.4.2.6 LOCATION AND LAYOUT

The ducts of ESF air cleaning systems that pass through clean areas should be designed at a higher negative pressure, and the length of any air cleaning unit positive pressure discharge ducts that must pass through a clean space should be kept as short as possible. When an ESF air cleaning system is a habitability system, ducts carrying outside air that are routed through clean space should be designed at a negative pressure. Housings handling recirculated habitability air should be at a positive pressure when located in a contaminated space. Negative pressure ducts located in a contaminated space should be avoided. When this is not possible, all-welded duct construction should be used. The length of positive pressure ducts outside the habitability zone should be kept as short as possible.

Generally, the direction of airflow should be from less contaminated spaces toward areas with a higher level of contamination. All ducts and housings containing a contamination level higher than surrounding areas should be maintained at a negative pressure. Ducts and housings with lower concentration levels than surrounding areas should be at a positive pressure. Allowable leakage depends on the difference between duct/housing concentrations and surrounding area concentrations. For example, a once-through contaminated exhaust filter housing serving a radioactive waste handling area in a nuclear power plant may have the exhaust fan located downstream of the filter housing when the housing is located in a space that is cleaner than the air entering the housing. The benefit of this system configuration is that the air cleaning system is under a negative pressure up to the fan. Therefore, leakage will be into the housing, and the potential impact of contaminated leakage on plant personnel during system operation will be minimized.

Such a system configuration does not mean that leakage can be ignored. Rather, it means the potential for exposure has been reduced to ALARA levels by system design. When the space in which an air cleaning system housing is located is more contaminated than the air entering the housing, it would be better to locate the fan on the inlet side of the housing to eliminate in-leakage of more contaminated air.

When the housings of habitability systems are located within a protected space, the fan should be located downstream of the filter unit to ensure that only cleaner air can leak into the housing. When the housing of a habitability system is located in an area outside a protected space, the fan should be located upstream of the filter unit to ensure that contaminated air cannot leak in downstream of the filter unit.

Location of fans and housings should be accomplished by assigning a positive designation to the atmosphere in the cleaner area or duct, and a negative designation to the more contaminated area or duct. When the pressure difference within an air cleaning housing or duct is positive (+), the fan should be on the contaminated air-entry side; when the pressure difference is negative (-), the fan should be on the "clean air" exit side.

Serviceability and maintainability are major considerations when designing an ESF air cleaning system. Access for servicing the inside and outside of the housing for filter replacement, maintenance, and testing must be provided. Housings should not be situated among machinery, equipment, and ductwork with any means for ready access. There must also be sufficient space in the access corridors and adjacent to the housing to allow handling of filters during change-outs, including space for stacking filters adjacent to the work area. Dollies are often needed to transport filters through the access corridors. When Type III carbon adsorbers are used, access to the area must be provided for the mobile carbon transfer equipment. Note that the fill method must be qualified to ensure adequate packing density. Hand filling is not acceptable. Recommended service clearances are given in ASME N509.[23]

2.4.2.7 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT NON-SAFETY-RELATED SYSTEMS

For non-safety-related system applications, applicable regulations, codes, and standards must be combined with good engineering practice. In addition, ease of maintenance, operability, testability, cleanability, and decontamination must be carefully considered. Air cleaning systems also must be integrated into the overall plant or process design, including monitoring and control requirements. Non-safety-related systems are not supplied with plant emergency power and, therefore, may not be operational during or after a DBA.

Design Considerations

Similar to ESF Systems, a clear definition of the design parameters is probably the most important, but often least appreciated, requirement for development of a satisfactory air cleaning system. The design parameters must consider basic performance requirements, physical limitations, and compliance with regulations, codes, and standards. All of these parameters must be identified as an initial design step because they are the basis for the system design.

Design Requirements

Section 2.2 lists common system design requirements. These requirements must be carefully considered because they lead to a safe, efficient, cost-effective system.

System Design

Individual non-ESF air cleaning systems are limited by Regulatory Guide 1.140[49] to approximately 30,000 cfm. When the system airflow exceeds this limit, multiple systems must be used in parallel. Non-ESF systems contain the following sequential components: (1) a moisture separator to remove entrained water droplets, (2) pre-filters, (3) HEPA filters, (4) a charcoal adsorber, (5) and a fan. Also included are ducts, valves, and dampers for system isolation and flow control, as well as related instrumentation. When moisture and dust loads are low for all credible operating modes, the prefilter and moisture separator may not be required.

Structural And Seismic Design

Ductwork for supply and exhaust systems should be supported seismically so that, where it runs adjacent to or over safety-related equipment systems, equipment, or components, failure of the supports cannot allow the ductwork to fall and damage these items. Article AA-4000 of ASME AG-1[30] provides the requirements for structural design of these supports.

Housings for these air cleaning systems should be designed to seismic Category II requirements. They are not required to be operational during or following an earthquake or other design basis event, but they need to remain structurally intact so that they spread potentially contaminated material into adjacent areas if a structural failure occurs.

Air Cleaning System Integration with the Entire Facility

The same considerations outlined for ESF systems should be observed for air cleaning system integration with other systems in the facility.

Design Areas Requiring Special Attention

The same considerations outlined for ESF systems should be observed for areas requiring special attention. See Section 2.4.2.

Location and Layout

The same considerations outlined for ESF systems should be observed for location and layout. See Section 2.4.2.6.

2.4.2.8 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT CONTROL ROOM SYSTEMS

The operation of a nuclear power plant is complex and must be performed with great care. Although there are a number of locations where control over operations is exercised at a nuclear power plant, the center of activity is the Control Room. Broadly described, the Control Room is a dedicated area at any type of nuclear facility where the plant operations controls are located.

Nuclear power plant operators are highly trained and licensed individuals. The primary function of Control Room operators is to control the nuclear reaction to ensure the reactor is operated safely under both normal and abnormal conditions. Therefore, the Control Room design must ensure that environmental conditions allow achievement of this goal. Both Control Room operators and equipment (electrical equipment, cables, gauges, instruments, controls, computers) must be protected from the radiation and radioactive material present during normal operation and during abnormal or accident situations, as well as toxic gases, fires, explosions, missiles, earthquakes, tornadoes, HELB, and floods. Control Room operators and equipment also must be provided an environment where both temperature and RH are maintained to ensure the continuing performance of the Control Room equipment and to provide reasonable standards of human comfort for the operators. The primary means of achieving these conditions are air cleaning, ventilation, and air-conditioning systems that are appropriately designed, tested, maintained, and operated in conformance with the facility design criteria and best engineering practices. In addition, to assist operator performance, the Control Room environment must be free from excessive noise, equipped with adequate lighting, and be designed with easy accessibility to equipment controls.

Control Room System Design Criteria

The basic regulation applicable to nuclear station Control Room systems is 10 CFR Part 50, Appendix A, “General Design Criterion 19.”[3] The regulation states, "A Control Room shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions, including loss-of-coolant accidents. Adequate radiation protection shall be provided to permit access and occupancy of the Control Room under accident conditions without personnel receiving radiation exposures in excess of 5 rem whole body, or its equivalent to any part of the body, for the duration of the accident." Control Room habitability during a postulated hazardous chemical release also is the subject of two regulatory guides. Regulatory Guide 1.78, “Assumptions for Evaluating the Habitability of a Nuclear Power Plant Control Room During a Postulated Hazardous Chemical Release,”[36] identifies chemicals which, when present in sufficient quantities, could result in the Control Room becoming uninhabitable. Design considerations to assess the capability of the Control Room to withstand hazardous chemical releases either on site or within the surrounding area are covered. SRP 6.4, “Control Room [39] contains guidance for reviewing Control Room ventilation systems and control building layouts, and is intended to assure that plant operators are protected against the effects of accidental releases of toxic and radioactive gases. The area served by the Control Room emergency ventilation system must be reviewed to verify that all critical areas requiring access in the event of an accident are included within the area (Control Room, kitchen, sanitary facilities, and computer facilities). The ventilation system layout and functional design must be reviewed to determine whether flow rates and filter efficiencies will be adequate to prevent buildup of toxic gases or radioactive materials inside the Control Room after an accident. Outside air intake locations for the Control Room must be reviewed to determine the potential release points of hazardous airborne materials to assure that such airborne materials cannot enter the Control Room.

The details of the ESF atmosphere cleanup system, including the credit to be assigned to the filtration system for iodine and particulate removal for use in dose calculations, are covered in SRP 6.5.1.[39] This information is identical to the information specified in Regulatory Guide 1.52.[17] The remainder of the Control Room area ventilation system is reviewed under SRP 8.4.1.3[9] A functional review of this system must be performed, including components such as air intakes, ducts, air-conditioning units, filters, blowers, isolation dampers or valves, and exhaust fans.

Control Room fire protection (for fires occurring either inside or outside the Control Room) is described in SRP 9.5.1.[39] Section 6.4 presents specific details concerning the applicability of fire protection features to assure Control Room habitability under all required operating conditions.

SRPs 12.3 and 12.4[39] provide guidance for radiation protection design features. Occupational radiation exposures are to be kept within ALARA limits by using appropriate shielding and air cleaning. Additional details on this subject are provided in Chapter 11.

The criteria for the design, installation, operation, testing, and maintenance of Control Room air cleaning systems have a single objective: to provide a safe environment in which the operator can keep the nuclear reactor and auxiliary systems under control during normal operation and can safely shut down these systems during abnormal situations to protect the health and safety of the public and plant workers.

Basic Control Room Layout

The entire Control Room envelope is serviced by the Control Room emergency ventilation system. All areas that require access in the event of a nuclear accident are included within this envelope. The Control Room emergency zone includes all of the instruments and controls needed for safe shutdown, the critical reference files, the computer room (when used as an integral part of the emergency response plan), the shift supervisor's office, a washroom, and a kitchen. Battery rooms, cable spreading rooms, switchgear rooms, motor control center rooms, and other spaces that do not require continuous or frequent occupancy after an accident are generally excluded from the Control Room emergency zone. However, these areas need to be provided with nuclear-safety-related cooling for essential equipment during and following DBAs. While these areas usually do not require the same level of protection from radiation and contaminants as the Control Room, their cooling systems (air handling and water cooling) should meet all of the other requirements.

Control Room General Ventilation Criteria

Control Room ventilation criteria Control Room are based on the premise that contaminants must be kept outside the Control Room. Therefore, Control Rooms are maintained at a positive pressure with respect to their immediate environs to assure that all air leakage flows out of the Control Room. The ventilation system should be capable of providing fresh outside air at a rate of at least 10 air changes/hr to dissipate any internally generated carbon dioxide or other noxious fumes. The system also should be capable of introducing outdoor air into the Control Room at a rate of at least 15 cfm per occupant. There should be no noticeable drafts to disturb operators or documents. In addition, the ventilation system must take care of the Control Room cooling and heating loads.

Control Room Temperature and Relative Humidity

The Control Room HVAC system Control Room must be capable of maintaining a comfortable temperature and relative humidity range, generally considered to be 73 degrees Fahrenheit (23 degrees Celsius) to 78 degrees Fahrenheit (26 Celsius), and 20 percent to 60 percent RH (ASHRAE Comfort Standard 55-74).[44] A secondary criteria is that the air temperature at floor and head levels should not differ by more than 10 degrees Fahrenheit (5.6 degrees Celsius).

Effective temperature, which takes into account dry bulb temperature, relative humidity, and air velocity, is commonly used as a measure of maximum limit for reliable human performance. The maximum effective temperature for reliable human performance is believed to be 85 degrees Fahrenheit (29 degrees Celsius). As extremes, this effective temperature can be achieved with 100 percent humid air at 85 degrees Fahrenheit (29 degrees Celsius), or with 20 percent humid air at 104 degrees Fahrenheit (40 degrees Celsius). Air velocity under 100 fpm (30.5 m/min.) has a negligible effect on effective temperature. Effective temperature is not intended to be used as a design criterion, only as a guideline for limiting operating conditions. Because relative humidity is not normally measured in a Control Room, a worst-case condition should be assumed, implying that a dry-bulb temperature of 85 degrees Fahrenheit (29 degrees Celsius) should be the maximum temperature for a Control Room. This temperature should not be exceeded for longer than 1 hr, after which steps should be taken to reduce the temperature. Previous regulatory requirements in this area were based on equipment qualification only, and required temperatures were to be kept under 120 degrees Fahrenheit (49 degrees Celsius). This is too extreme for an operator to function efficiently and has been revised.

Control Room Air Composition

Clean air for operator breathing can be compromised by radioactive as well as chemically toxic gases. Chlorine is used extensively at nuclear power plants, and is the principle toxic gas of concern. With respect to radioactive materials, the air composition is specified in 10 CFR 20, Appendix B, Table 2.[1] The concentration limits specified for every radionuclide are given as the maximum allowable airborne radioactive material concentrations to occupational workers during normal operations. During an accident, the HVAC system must be designed to limit the dose to the Control Room operator to 30 rem thyroid exposure.

TABLE 2.12 below lists the maximum allowable 2-min concentrations of various toxic gases.[65] As stated in Regulatory Guide 1.78,[36] these limits are considered the maximum concentrations that can be tolerated for 2 min without physically incapacitating an average human (by severe coughing, eye burn, severe skin irritation, etc.). A benchmark of 2 min is used because the operator is expected to continue functioning by donning a self-contained breathing apparatus within 2 min. The designer must verify that sufficiently large quantities of these toxic gases are not stored or transported in the Control Room environs where, under adverse meteorological conditions, failure of the toxic gas containers would exceed the toxicity limits.

Table 2.12 – Toxicity Limits Table

CHEMICAL CONTAMINANT	2-Min Toxicity Limit, ppm
Carbon dioxide	1.0 percent
Carbon monoxide	0.1 percent
Chlorine	15
Acetaldehyde	200
Acetone	2,000
Acrylonitrile	40
Anhydrous ammonia	100
Aniline	10
Benzene	50
Butadiene	0.1 percent
Butenes	Asphyxiant
Ethyl chloride	10,000
Ethyl ether	800
Ethylene dichloride	100
Ethylene oxide	200
Fluoride	2
Formaldehyde	10
Helium	Asphyxiant
Hydrogen cyanide	20
Hydrogen sulfide	500
Methanol	400
Nitrogen	Asphyxiant
Sodium oxide	2 (*)
Sulfur dioxide	5
Sulfuric acid	2 (*)
Vinyl chloride	1,000
Xylene	400

* mg of particulate per m^3 of air at 25 degrees Celsius and 760 mm of mercury.

Table 2.12 above specifies a toxicity limit of 15 ppm for chlorine, the only toxic gas widely used. Therefore, protection from a chlorine release is required. Control measures, as outlined in Regulatory Guide 1.78,[36] include (1) automatic isolation of the Control Room, (2) a leaktight Control Room, or (3) equipment and procedures for ensuring the use of a protective breathing apparatus by the Control Room operator(s). Measurement should be at or near the air intake, and a 5-ppm detection limit should automatically activate the emergency control system.

Control Room Noise Levels

Verbal communication is necessary for efficient Control Room operation. Background noise, particularly from the HVAC systems serving the Control Room, should not impair this communication. Background noise levels should not exceed 65 dB(A), and sound absorption should be sufficient to limit reverberation time.

Control Room Fire Protection Criteria

Fire Events Inside the Control Room

For fire events inside the Control Room, the design must ensure that plant shutdown capability, independent of the Control Room, is provided. With respect to ventilation, means should be provided to remove combustion products from the Control Room. Smoke detectors are necessary to alert Control Room operators of a fire, and should be located in Control Room cabinets, consoles, and air intakes. The location of air supply intakes must be remote from all exhaust air and smoke vent outlets. The outside Control Room air intakes and all recirculation portions of Control Room ventilation systems need manual-isolation fire and smoke dampers. Peripheral rooms within the Control Room emergency ventilation zone should have fire dampers that close when the fire detection or fire suppression system begin operation.

Fire Events Outside the Control Room

The Control Room complex should be separated from the remainder of the plant by fire dampers. Important HVAC fire protection features, in addition to detection, include:

- Fire suppression
- Qualified penetration seals for all penetrations
- Portable blowers for smoke removal
- Location of all ventilation intakes and exhausts in relation to fire hazard

2.4.2.9 CONTROL ROOM VENTILATION SYSTEM ARRANGEMENTS

The influx to a Control Room of radioactive and other contaminants can be eliminated by a ventilation system designed to filter the inlet air and by pressurizing the room to ensure that any leakage will be out-flowing. Design alternatives include one-pass purified outside air, recirculation purified air, stored bottled air, and a choice of dispersed air inlets.[45] Each system has a different application, with advantages and disadvantages. This section will discuss the four types, present models for calculating doses to the Control Room operators, and associated air cleaning requirements.

Isolation with Purified Air Pressurization

In this concept, the Control Room is automatically isolated in response to an accident alarm or a high radiation signal at the fresh air inlets. The operator then has the option of manually initiating emergency pressurization using make-up air that is directed through a standby air purification system. Pressurization flow rates are normally in the range of 500 to 5,000 cfm.

Although isolation alone is normally sufficient for accidents of short duration, or for an accident where the activity release is of short duration, purified air pressurization would be necessary for long-duration and high-activity situations. The iodine protection factor, which is defined as the dose assuming no iodine removal divided by the dose assuming iodine removal, would be expected to be approximately 20. In addition, even with the filter system in operation, noble gas activity will pass through the air cleaning system and be drawn into the Control Room to contribute to the whole body gamma exposure. Thus, it is prudent to modify the air cleaning system to allow it to be used in either the recirculation or pressurization mode.

Isolation With Purified Air Recirculation

In this concept, the Control Room is automatically isolated for purified air pressurization, but the air purification system is automatically activated in the recirculation mode. Control Room air is withdrawn, purified, and returned to the Control Room as shown in The leaktightness of the Control Room, or more specifically the calculated activity level of the purified air in-leakage, determines the required recirculation rate. Typical rates are in the 5,000 to 15,000 cfm range. This Control Room ventilation design is the one most commonly seen at commercial nuclear power plants.

Isolation With Purified Air Pressurization and Recirculation

The third option is to manually pressurize the Control Room with purified outside air, while most of the Control Room air is simultaneously recirculated through a second air purification unit. This leads to very high iodine protection factors. Pressurization minimizes the amount of unfiltered air that can infiltrate the Control Room, and a high level of leaktightness for the Control Room becomes less important. The disadvantage of a leaktight room is that noble gas exposure may increase due to back-flow of contaminated air when doors are opened or closed. Back-flow can be reduced and even eliminated when protection devices such as two-door air locks are installed. In practical terms, isolation with recirculation limits the entrance of noble gases and is the preferred operating mode when an accident involves a short-term puff release. Isolation with pressurization and recirculation minimizes infiltration, and the addition of a second air purification unit in the air inlet duct (assuring double filtration of make-up air) makes the ventilation system extremely effective against contamination.

Bottled Air

The feasibility of using bottled air to maintain a Control Room above atmospheric pressure depends on the presence of a specific type of containment system for the nuclear reactor. In some designs, containment pressure will be reduced below atmospheric pressure within 1 hr after a DBA, restricting significant releases to within this 1-hr period. When the Control Room can be completely isolated for 1 hr (allowing no personnel ingress or egress), sufficient bottled air may be kept on site to pressurize the Control Room to 1/4 in.wg. Under these circumstances, 300 to 600 cfm (70-140 cylinders charged to 2,400 psi) should be sufficient to maintain adequate pressurization. As there may be accident situations where activity releases from buildings other than containment can continue for periods much longer than 1 hr, a once-through system for continued pressurization is also required.

Multiple Dispersed Inlets

This concept utilizes two or more remotely located inlets. They are placed so that all potential release points lie between them, assuring that one inlet can supply contamination-free air at all times. This source of fresh air is used to pressurize the Control Room to minimize infiltration.

Clearly, the usefulness of the multi-inlet concept relies on the placement of inlets to assure that one inlet is always free of contamination. Selection depends on building wake effects, terrain, and the existence of wind stagnation or wind reversal. Possible inlet locations are at the edges of the plant structure (e.g., one on the north side and one on the south side). Under certain conditions, all inlets could be contaminated from the same point source, but the probability of a release reaching all inlets would be drastically reduced. It is important to review all potential sources of contamination, including toxic material containers, to verify that simultaneous contamination of all inlets is impossible. Nonetheless, it is recommended that a once-through air purification system for make-up air be included as a backup in any design using multiple inlets.

The system must ensure that no flow is allowed through the closed inlet. Ducting must be designed as seismic Category I and protected against tornadoes and missiles. The dampers must be single-failure proof and bubble-tight. It is important to note that, whichever method is chosen, care must be exercised in designing, constructing, and maintaining control room air leakage (see Control Room Infiltration below).

Control Room Dose Evaluation

Acceptable levels of radioactive contaminants in the Control Room and dose commitments are included in **TABLE 2.13**. The three dose commitment objectives of concern are listed below.

- Whole body gamma radiation from direct-shine radiation of sources external to the Control Room and from airborne activity within the Control Room
- Beta skin dose from airborne activity within the Control Room [The dose is evaluated by assuming a 7 mg/cm^2 depth dose (to account for the shielding effect of the insensitive superficial skin layer) and semi-infinite cloud geometry.]

Thyroid dose from the inhalation of radioactive iodine [A breathing rate of 3.47×10^{-4} m^3/sec, and the International Commission on Radiological Protection (ICRP) Publication No. 2 parameters[46] should be assumed.]

Table 2.13 – Acceptable Levels of Contaminants and Dose Commitments in the Control Room

[AUTHOR'S NOTE: TABLE TO BE DEVELOPED]

Each of the three dose components can be calculated on the basis of source strength, atmospheric transport, dosimetry, and Control Room protection considerations.

Purge Factor

Control Rooms characterized by a high degree of leaktightness benefit from the relatively slow build-up of activity within an isolated Control Room followed by a purge of the Control Room atmosphere at appropriate times after a release.

Given a finite isolation time, a nonequilibrium buildup of activity in the Control Room followed by a purge will result in a lower dose than in the case of instant equilibrium. The ratio of equilibrium to transient doses for an isolated Control Room followed by a purge is given by:

$$PF = 1 - \frac{\ }{Rt}(1-e^{-Rt})$$

where:

PF = purge factor

R = air exchange rate, air changes/hr

t = isolation time, hrs

The purge factor is based on assumptions that the Control Room is immersed in a cloud of constant activity concentration for a period of "t" hrs and is instantaneously purged of activity immediately after the cloud passes. A conservatively large value of "t" should be used, depending on the specific circumstances, since the operator must (1) recognize that the external activity has fallen to a low value and (2) manually initiate Control Room purging. For most accident sequences, it is reasonable to assume that several days will elapse before conditions warrant purging.

Control Room Infiltration

Infiltration is defined as unintentional leakage of air into the Control Room caused by pressure differences across the boundary of the Control Room air space. Typical leak paths are cracks around the door frames; duct, pipe, and cable penetrations; structural joints; and damper seals. Good Control Room design minimizes leakage paths by using gaskets, weatherstripping, and sealing techniques. However, continuous distributions of microscopic capillaries and pores in concrete are possible, making complete elimination of infiltration difficult.

Pressure differentials may be due to natural phenomena such as wind and temperature or barometric differences. Pressure differences can also occur when there are flow imbalances between the Control Room and adjoining spaces.

Precise evaluation of Control Room infiltration is difficult to predict in the design phase because of the many variables (e.g., wind direction and speed, building geometry, Control Room leaktightness, internal building pressure distribution) that can combine in different ways. In addition, the degree of Control Room isolation after an accident associated with ingress/egress traffic further compounds the situation. One approach is to measure infiltration at a number of Control Rooms and analyze the data. An isolated Control Room can be pressurized to determine the pressurization flow rate required to maintain a constant pressure. Tracer gases may also be used in a series of concentration decay measurements under various atmospheric conditions to establish empirical correlation between Control Room configuration, construction quality, ventilation characteristics, and infiltration characteristics. A study performed at the Zion Generating Station in (Zion, Illinois) using sulfur hexafluoride provided extremely useful results.[48] Sulfur hexafluoride was used because it is nontoxic, nonreactive, inert, and easily detectable by electron capture gas chromatography. With a measured make-up flow of 1,700 cfm, total infiltration leakage was experimentally determined to be 150 cfm. This was reduced by 50 percent when simple corrective measures were taken (new gaskets).

Air Cleaning Criteria

The most important feature of a Control Room air cleaning system is its ability to deliver sufficient quantities of clean air to the Control Room so that operators can perform their assigned duties in comfort and safety.

During normal operations, the Control Room ventilation system keeps out dust and noxious contaminants and maintains effective temperature at acceptable levels. It also keeps the Control Room pressurized to 1/4 in.wg to prevent in-leakage. During an accident situation, the Control Room air cleaning system must continue to function and provide a habitable environment for the Control Room operators. The system must be designed to seismic Category I and must be redundant to satisfy the single failure criterion. Automatic activation is necessary. Design features and the qualification requirements of an ESF Control Room air cleaning system are contained in Regulatory Guide 1.52[17] and ASME Code AG-1.[30] The components included in each of the redundant filter trains are: (1) demisters to remove entrained moisture, (2) prefilters to remove the bulk of the particulate matter, (3) HEPA filters, (4) iodine adsorbers (generally, activated carbon), (5) HEPA filters after the adsorbers for redundancy and collection of carbon fines, (6) ducts and valves, (7) fans, and (8) related instrumentation. Heaters may be used to reduce the RH entering the carbon beds to maximize performance and remove radioiodine species. **FIGURE 2.4** is a schematic of an ESF air cleaning system.

Subsystems

Cable Spreading Rooms. These rooms contain the cables that are routed to the Control Room. They are normally cooled by a 100 percent recirculation air conditioning unit that is nuclear safety-related and has an assured (nuclear-safety-related) source of cooling to maintain the space temperature for all applicable design basis events. This unit may be a part of the control complex HVAC system.

Emergency Electrical Switchgear Rooms. These rooms contain the essential switchgear for the plant. They are normally cooled by a 100 percent recirculation air conditioning unit that is nuclear safety-related and has an assured (nuclear-safety-related) source of cooling to maintain the space temperature for all applicable design basis events. This unit may be a part of the control complex HVAC system.

Battery Rooms. The essential battery rooms contain the batteries that provide back-up power for certain design basis events. They should be designed for a maximum room temperature of 77 degrees Fahrenheit (25 degrees Celsius) per IEEE Standard 484[58] and should be provided with an assured (nuclear-safety-related) source of cooling. These batteries also produce hydrogen when they are being charged. Therefore, a nuclear safety-related exhaust system is required that provides a minimum of five room air changes/hr. Also, the exhaust pick-up points must be at the ceiling of these rooms because hydrogen is lighter than air and will pocket at the highest point in the room.

Testability

Qualification testing and quality assurance of individual components by manufacturers in accordance with ASME N509,[23] ASME Code AG-1[30] and ASME NQA-1[48] is required. After installation, pre-operational tests on individual components and the complete system are necessary. Deficiencies need to be repaired prior to accepting the system for operation and subjecting the system to radioactive contamination. An operating system must undergo periodic surveillance testing to verify that it can continue to perform its intended function. Technical Specifications, a part of the license for each nuclear power station, define the limiting conditions for operation (LCO) and the surveillance requirements for satisfying the LCOs. The LCOs specify which actions must be taken if the system becomes inoperable. The surveillance requirements are contained in Regulatory Guide 1.52,[17] ASME N510[34] and ASME Code AG-1[30]

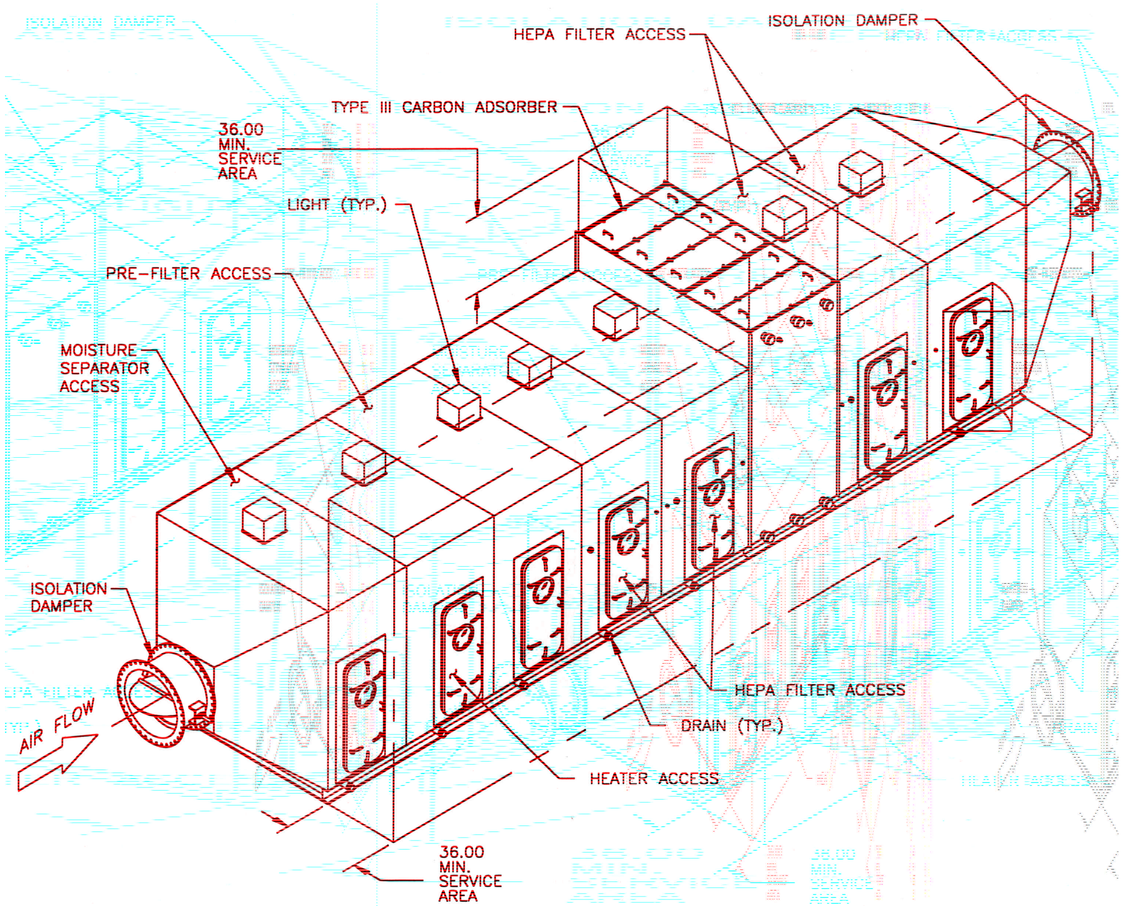

Figure 2.4 – Typical air cleaning system

Regulatory Inspection Activities

Inspections of Control Room ventilation and radiation protection provisions for Control Room personnel are performed during the construction, pre-operational, and operational stages. In the United States, regional staffs perform this function at nuclear power plants. Inspection guidance is contained in manuals in the form of inspection modules. Inspections are performed to ensure that all systems will perform their intended function, that operating procedures are in place, and that training has been provided.

Control Room Habitability Experience

Licensee Event Reports (LERs) submitted to the NRC by operators of commercial nuclear power plants are a useful source of information on the performance of habitability systems in Control Rooms, as well as other air cleaning systems. It is important to evaluate them, and factor the lessons-learned into future activities. Owners of commercial nuclear power plants evaluate LERs through their Operating Experience Program.

2.4.3 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT AUXILIARY BUILDING SYSTEMS

The auxiliary building area of the plant houses all of the safety-related systems and equipment required to safely shut down the plant in the event of a design basis event. Air handling and cleaning systems serving the auxiliary building consist of a mixture of safety-related and non-safety-related systems.

Supply Systems

Supply systems are generally non-safety-related. Their purpose is to supply outside air for personnel and equipment cooling and for make-up air to those systems that exhaust air from contaminated spaces. This supply air should be introduced into "clean" areas of the building and should be designed to flow toward areas where contaminated air is exhausted. Cooling coils may be used to reduce the outside air temperature when design outside air temperatures dictate. The cooling medium is usually plant service water from the non-safety-related service water system. Heating coils are used to prevent the cooling coils from freezing and to supply heat to the outside air to prevent the building temperature from dropping too low. The heating medium is usually steam or hot water from the plant's heating system. Inside design temperature should be a maximum of 104 degrees Fahrenheit (40 degrees Celsius) for electrical equipment and personnel comfort considerations. The minimum inside temperature should be 60 degrees Fahrenheit (16 degrees Celsius) to provide comfort for personnel and to ensure plant areas do not freeze.

For rooms that contain the Emergency Core Cooling System (ECCS) pumps, either the pump motors are water-cooled or nuclear-safety-related pump room coolers are provided. If pump room coolers are used, they are 100 percent recirculation and are supplied with cooling water from the plants' emergency raw water cooling system. When the pumps themselves are redundant, it is not necessary to supply redundant room coolers.

Precautions

Outside air intakes for the supply system should be located where exposure to smoke, fire, and potential contaminated air release points is at a minimum. They should be equipped with isolation dampers in the event that isolation of a particular supply point is necessary to mitigate any of these effects. In addition, since these openings are usually large and are vulnerable to both missile and negative pressure effects from tornadoes, provisions must be made to ensure that missiles cannot enter the building and damage safety-related equipment. Protection can be provided via a network of steel bars in these openings. However, allowance for the blockage caused by these bars must considered when sizing the openings. Placing tornado dampers immediately downstream of the openings can minimize the effects of the negative pressure caused by a tornado (approximately 3 psig). This prevents potential damaging effects such as damage to ductwork or air handling equipment.

Exhaust Systems

Exhaust systems are usually both safety-related and non-safety-related. Areas that need not be operational during or after a design basis event are usually served by non-safety-related exhaust systems. While these systems are not redundant, it is prudent to design them so that they have some operational flexibility. For example, air cleaning units may be provided at 50 percent capacity each, and each unit should have its own fan. This will ensure that some exhaust capability is maintained during periods when one of the units is off-line for repair or maintenance. Air cleaning units usually consist of prefilters, HEPA filters, and an adsorber. Moisture separators may be employed if entrained moisture is a routine concern. All exhaust systems must be routed to a common release point (sometimes known as the unit vent stack) so that all potentially contaminated air can be monitored for radioactivity.

Safety-related exhaust systems (ESF systems) are required wherever there is a potential for release of contaminated air in the event of a DBA. Sources of contaminated air are usually the engineered safeguards pump and heat exchanger rooms, where there is a potential for pump seal or gasket failure during the event. These areas are required to be maintained at ¼-in.wg negative pressure with respect to the outside environment and adjacent areas. This is an NRC requirement. Housings, ductwork, and supports for these systems are to be built to seismic Category I standards. Article AA-4000 of ASME AG-1[30] provides the requirements for structural design of these housings and supports.

Precautions

The US NRC requirement to maintain the pump and heat exchanger rooms at a negative pressure during and after a design basis event requires an extensive review of the potential air leakage paths during design, construction, and operation of the auxiliary building. These leak paths can be from many sources, including building penetrations for pipe and cable, doors, etc. The most common type of problem penetrations are the doors. Doors should be provided with seals to minimize leakage, along with operational controls that require doors leading into or out of the auxiliary building to be closed at all times except for entry/exit. Doors that must remain open for an extended period must be monitored continuously during the activity and must be able to be closed upon command from the Control Room. Penetrations for pipe and cable are usually less of a concern because they are provided with fire seals that should also serve as air seals.

Periodic testing is required to demonstrate that the safety-related areas of the auxiliary building can be maintained at the required negative pressure. It is strongly recommended that all safety-related air handling and cleaning systems that have either a positive or negative pressure requirement be tested at the same time, because it has been determined that there are interactions between systems that can influence the pressure in another area of the plant. Some cases have been found where the worst scenario is not a loss of power (where only the safety-related systems are in operation), but rather where all or a portion of the non-safety-related systems are operating together with the safety-related systems. Therefore, some experimentation with various combinations of system operation is required to find the worst case testing condition.

2.4.4 Air Cleaning System Design Considerations for Commercial Nuclear Power Plant Spent Fuel Pool Systems

The spent fuel pool area of the plant contains the storage pool for radioactive spent fuel that has been removed from the reactor. The air cleaning systems serving this area generally have the same requirements and design considerations as those for the Auxiliary Building.

Supply Systems

See description and precautions for Auxiliary Building Supply Systems contained in 2.4.3.

Exhaust Systems

Exhaust systems for the spent fuel pool are ESF systems. See the description and precautions for the safety-related portions of the Auxiliary Building Exhaust Systems contained in 2.4.3.

To ensure that any off-gas from the spent fuel pool itself is captured, a good method is to embed exhaust ducting in the upper portion of the concrete that forms the pool. This ducting should have multiple suction points that are close to the surface of the pool. When designing this ductwork, structural provisions must be made to assure that the ductwork does not collapse when the concrete is being poured on and around the ductwork and while it hardens. In addition, drains should be provided inside the ductwork to drain away any water that may condense there or get into the suction points caused by sloshing of the water in the pool. This portion of the exhaust should be constructed of stainless steel (ductwork, reinforcing, support, etc.) to prevent corrosion.

2.4.5 Air Cleaning System Design Considerations for Commercial Nuclear Power Plant Shield Building Systems

The shield building is the annular space between the primary steel containment and the secondary concrete containment. Not all commercial nuclear power plants have this annular space. Many early plants were built with a concrete containment and a steel liner that are directly in contact with each other. Later plants were built with a space between the two to enable inspection of both sides of the steel primary containment for leakage. Air cleaning systems for the annular space provide assurance that any leakage from the primary containment is treated before release to the environment.

Supply System

There is no supply system for the shield building. All exhaust air comes from leakage through the penetrations of the concrete containment because the primary steel containment and its penetrations are designed to be airtight.

Exhaust System

Exhaust systems for the shield building are nuclear safety-related (ESF systems), redundant, physically separated, and supplied with assured power from the plant's Class 1E emergency power system. All of the requirements for ESF systems must be met. The system is arranged such that there is an ability to exhaust and/or recirculate air from the shield building. When the system is actuated for testing, or in the case of a design basis event, the system will initially draw down the annular space to a predetermined negative pressure (specific to each plant design) and will be in 100 percent exhaust mode. Once this negative pressure has been achieved, the system will begin to modulate (begin to recirculate a percentage of the total air flow) to maintain the shield building at this negative pressure to ensure that any leakage into the shield building is in-leakage and is treated before release. Rather than modulating, some shield building systems will go into a 100 percent recirculation mode once the building has reached the required negative pressure. The system then stays in recirculation until in-leakage causes the pressure to rise to a predetermined value. This value is still negative. Once this upper limit is reached, the system will switch to 100 percent exhaust and the cycle will repeat itself as long as operation of the system is required.

Housings and ductwork for these systems are to be built to seismic Category I standards. Article AA-4000 of ASME AG-1[30] provides the requirements for structural design of these housings, ductwork, and supports. The exhaust ductwork is routed to a common release point (the unit vent stack) so that the potentially contaminated air can be monitored for radioactivity.

Precautions

The NRC requirement to maintain the shield building at a negative pressure during and after a design basis event requires an extensive review of the potential air leakage paths during the design, construction, and operation of the shield building. These leak paths can be from many sources, including building penetrations for pipe, cable, ductwork, instrumentation/control lines, doors, etc. The most common type of problem penetrations are the pipe, cable, ductwork, and instrumentation/control penetrations through the secondary concrete containment. The primary steel containment penetrations are airtight and are usually not a problem. All pipe, cable, ductwork, instrumentation/control penetrations, and doors must be provided with seals to minimize leakage. In addition, operational controls must be established for these penetrations so that any time a penetration is breached for repair, replacement, or maintenance, it is continuously monitored until the work has been completed. A plan must also be in place to immediately seal the penetration upon command from the Control Room.

2.4.6 Air Cleaning System Design Considerations for Commercial Nuclear Power Plant Reactor Building Cooling and Atmosphere Cleanup Systems

The Reactor Building contains the reactor, reactor coolant system, steam generators (in pressurized water reactor plants), pressurizer, and associated safety and non-safety systems that support operation of the primary reactor systems. These components are surrounded and protected by the primary steel containment and the concrete secondary containment.

There are several air handling systems associated with the proper operation of the Reactor Building. These include:

- Reactor Building cooling systems
- Upper containment cooling systems
- In-core instrumentation room cooling system
- Reactor Building purge supply and exhaust system
- In-core instrumentation room purge supply and exhaust system
- Reactor Building recirculation atmosphere cleanup system

Reactor Building Cooling Systems

The Reactor Building cooling systems can be nuclear safety-related or non-nuclear-safety-related depending on the nuclear steam supply system (NSSS) vendor's design parameters. The containment temperature is regulated by the plant's Technical Specifications, which apply whether or not the containment cooling system is nuclear safety-related. The usual maximum temperature is 120 degrees Fahrenheit (49 degrees Celsius) and the minimum temperature is usually 60 degrees Fahrenheit (16 degrees Celsius). Temperatures outside the maximum and minimum require plant shutdown or, if the plant is already shut down, it cannot be restarted until the minimum temperature has been attained.

Some plants use the Reactor Building cooling system as one of the primary systems to remove energy released in the event of a design basis LOCA. These systems are nuclear safety-related and have two operational modes:

- Normal operation, where cooling water is pumped through cooling coils and the cooled air is distributed by a system of fans and ductwork to the main area of the lower part of the Reactor Building. These systems are 100 percent recirculation and all of the air handling equipment is contained within the Reactor Building.
- Abnormal operation, e.g., in the event of a LOCA, where the system fans switch to high speed and the flow of cooling water to the cooling coils is substantially increased to handle the large amount of energy released. These systems are simple in practice, but they require careful coordination between the plant owner, the architectural and engineering vendor responsible for the plant design, the NSSS vendor, and the vendor that supplied the fans, cooling coils, etc., to ensure that the correct design inputs are established. [Note that redundancy is not built into this type of Reactor Building Cooling System, as the system itself is redundant to other water cooling systems (injection, sprays, etc.) that respond to LOCAs.]

For Reactor Buildings that rely on all water or ice condensers to provide the necessary energy removal during a LOCA, the normal air cooling systems are non-nuclear-safety-related. These systems are designed for normal cooling loads only, and require extra capacity. Two-speed fans or variable drive fans and/or extra cooling units should be considered to provide extra capacity and partial redundancy. As much as 100 percent additional cooling capacity has been required during operation of some Reactor Building cooling systems operation as a result of losses due to poor fit-up or the metallic insulation used on primary reactor coolant piping, as well as portions of piping that are not insulated due to supports and restraints. Other sources of unanticipated heat can come from small water and steam leaks from the various systems inside the building. Like the safety-related systems described above, these systems are all contained within the reactor building and are 100 percent recirculation. A network of ductwork is used to distribute the cooled air to the primary areas of the Reactor Building. Some means for returning air from the upper portion of the containment is also needed, as well as from the area immediately adjacent to the reactor head/control rod drive mechanism.

Ice condenser plants present several special challenges for cooling of the Reactor Building. The reactor building is physically divided into two areas (upper and lower containment) by a concrete divider deck. This divider is necessary to prevent bypass of the ice condenser during a LOCA. Therefore, an upper containment and a lower containment cooling system are required. The lower containment system is identical to the system described above for non-nuclear-safety-related systems. However, the upper containment requires a separate system consisting of air handling units, water cooling coils, and ductwork for air distribution. In addition, the lower containment contains several dead-ended compartments that are provided for the steam generators and the pressurizer. It is necessary to provide exhaust from these compartments, as hydrogen can build up in them during a LOCA and reach explosive concentrations. The exhaust ductwork (piping buried in the concrete structures) and the exhaust fan are nuclear-safety-related. The exhaust is routed in close proximity to the containment air return fans and is mixed with recirculated containment air to reduce the concentration of hydrogen to below explosive limits (more on this system will follow). Another area that requires special consideration is the pipe tunnel that encircles the lower portion of the containment. This area requires separate ventilation (ductwork and fans) to ensure proper heat removal and ventilation.

It is noted that most early plants relied on water from lakes or rivers for the cooling medium for the containment coolers. The use of this water did not always properly take into account the effects of fouling, hotter-than-predicted water from ambient temperature extremes and droughts, lake inversion in the fall of the year, and, where low-level plant service water intakes were used, the use of all available cool bottom water before seasons changed to provide natural cooling. As a result of these lessons learned, many later plants were constructed with water chillers to provide chilled water for containment cooling, thus ensuring a supply of cool water. In addition, the plant service water system was designed to make use of cooling towers more frequently in later plant designs. These later plant designs also used lake or river water, or water from plant cooling towers, for the condenser side of the chillers where the service water temperature extremes can be more readily accommodated. When using lake, river, or cooling tower water for condensing water for chillers, however, it is considered a good precaution to take into account the minimum winter water temperature. Water that is too cold can cause a refrigerant pressure reversal in the chiller, preventing it from operating. The chiller vendor should be consulted for proper condenser water piping and flow control techniques to ensure this does not occur.

Upper Containment Cooling Systems

This portion of the Reactor Building cooling system uses a network of ductwork and fans to exhaust air from the upper part of the containment to remove the heat that rises to the top of the building during normal operation. The air is brought down from the upper containment and discharged near the intake portion of the main reactor building cooling units for cooling and recirculating. It is prudent to supply some extra capacity in this portion of the system. For example, the system should be designed for operation of three fans, but four should be provided. Experience has shown that simply exhausting this air may not be sufficient to maintain the upper containment temperature, and auxiliary coolers with water cooling coils have been installed to pre-cool the air before returning it to the main cooling units. This portion of the system is usually non-nuclear-safety-related.

In-core Instrumentation Room Cooling System

In-core instrumentation rooms require small, non-nuclear-safety-related, redundant, water-cooled air handling units to provide sufficient cooling for the electrical equipment associated with the in-core instrumentation. Early designs lacked this cooling equipment and required backfits. Very little distribution ductwork is required for these cooling units.

Reactor Building Purge Supply and Exhaust System

Reactor Buildings must be capable of purging the containment atmosphere of airborne radionuclides during reactor shutdown for refueling or maintenance. Initial designs for this system intended purging of the containment whenever warranted by the airborne activity. However, the US NRC has restricted large-volume purging during power operation due to concerns about the ability to quickly isolate the containment in the event of a design basis event.

This system is a non-nuclear-safety-related system with the exception of the purge system containment isolation valves. Containment isolation valves for air systems are usually zero leakage butterfly valves due to the large sizes required. All containment isolation valves are considered part of the primary steel containment and have special design, construction, and operational requirements that are governed by the plant's Technical Specifications.

The supply part of the system consists of an air handling unit with cooling and/or heating coils, shut-off dampers, containment isolation valves, and ductwork. This unit is used to introduce 100 percent outside air to the Reactor Building to serve as a cooling medium and make-up for the purge exhaust system. All system equipment and components are located in the Auxiliary Building with the exception of the supply ductwork and the isolation valves. The system flow rate is approximately 25,000 cfm.

The exhaust consists of an air cleaning unit with pre-filters, HEPA filters and adsorber, fan, shut-off dampers, containment isolation valves and ductwork. When in operation, it exhausts 100 percent of the air supplied by the purge supply system. All exhaust air is routed to the unit vent stack for monitoring prior to release to the environment. All system equipment and components are located in the Auxiliary Building with the exception of the Reactor Building portion of the ductwork and the isolation valves.

In-core Instrumentation Room Purge Supply and Exhaust System

The in-core instrumentation room purge supply and exhaust system is identical in concept to the Reactor Building purge supply and exhaust system except for the volume of air supplied and exhausted. The flow rate for this system is approximately 1,000 cfm.

Reactor Building Recirculation Atmosphere Cleanup System

The Reactor Building recirculation atmosphere cleanup system ensures the atmosphere inside the Reactor Building can be filtered to remove airborne radionuclides during periods when the reactor is at power and purging is not allowed. This allows the operator some flexibility with respect to cleanup of the containment atmosphere. This is a non-nuclear-safety-related system.

The system consists of an air cleaning unit with prefilters, HEPA filters, an adsorber, a fan, and minimal ductwork. When operating, it recirculates 100 percent of the air inside the containment (lower containment for ice condenser plants). All system equipment and components are located inside the Reactor Building.

2.4.7 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT FILTERED AND VENTED CONTAINMENT SYSTEMS

Containments Vented Directly to the Atmosphere

The air cleaning system for a containment that is vented directly to the atmosphere consists of a pressure vessel that contains up-and-down-stream HEPA filters and an adsorber. Ducting is constructed from pipe, and valves are used for shut-off and flow control to ensure pressure boundary integrity. This is a nuclear-safety-related system and all requirements for ESF systems apply.

Filtered Containments

The air cleaning system for a filtered containment is essentially the same as that described for the Reactor Building recirculation atmosphere cleanup system, with two significant differences. First, this is a nuclear-safety-related air cleaning system and all the requirements of ESF systems apply. Second, the system is located outside of the containment and employs containment isolation valves.

For either of these systems, care must be exercised to ensure the pressure has been equalized *before* operating the system so that damage to the filters does not occur.

2.4.8 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT CONTAINMENT AIR RETURN AND HYDROGEN SKIMMER SYSTEMS FOR ICE CONDENSER PLANTS

Ice condenser plants have special requirements that apply to the containment due to the use of ice beds that serve as one of the primary systems for removing the energy released in the event of a LOCA. The containment is physically divided into two areas (upper and lower] by a concrete divider deck. This divider deck is necessary to prevent bypass of the ice condenser when the steam/air mixture that results from a LOCA flows through the ice beds to remove the energy in this mix. The lower containment also contains several dead-ended compartments that are provided to house the steam generators and the pressurizer. It is necessary to provide exhaust from these compartments because hydrogen is formed during the chemical reaction that occurs during a LOCA, and the buildup of hydrogen pockets can reach explosive concentrations.

There are two primary components for this system. The first is the air return fan, which is a nuclear-safety-related fan located above the concrete divider deck. It is equipped with a motor-operated shut-off damper capable of withstanding the initial pressure surge from a LOCA of 15 psig. Two of these fans provide 100 percent redundancy. After the initial pressure surge subsides, the steam/air mixture begins to flow through the ice beds due to stack effect. In time, the stack effect of the flow through the ice beds is reduced and a mechanical means is needed to ensure continued flow through the ice and return the cooled air to the lower containment for further processing. The air return fan provides this means.

The second component of this system is the hydrogen skimmer fan, related ductwork, and dampers. [Note that pipe is used for ductwork and valves are used for dampers, as the majority of the network that forms the exhaust system is buried in the concrete surrounding the dead-ended cavities served by this system.] There are two 100 percent redundant hydrogen skimmer fans. These are located in close proximity to the air return fans, and they discharge the hydrogen/air mixture that they collect directly into the suction of the air return fans. This hydrogen/air mixture is then diluted by the much larger flow rate of the air return fans, and the concentration is reduced to below explosive limits. The air return fans, hydrogen skimmer fans, and the motors and controls associated with this system should be built to explosion-proof requirements. The Nuclear Stream Supply System (NSSS) vendor establishes flow rates for both the air return and hydrogen skimmer fans and the individual compartments.

2.4.9 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT DIESEL GENERATOR BUILDINGS

The plant emergency diesel generators are contained in separate, redundant buildings and supply emergency power when required by the applicable design basis events. The ventilation system serving these buildings usually consists of normal and emergency ventilation systems.

The normal system contains a prefilter, fan, electric heating coil, and ductwork that is sized for normal heating or cooling loads when the diesel generator is in stand-by mode. The system supplies 100 percent outside air with no recirculation. Inside design temperature is 104 to 110 degrees Fahrenheit (40 to 43 degrees Celsius) for summer conditions and 60 degrees Fahrenheit (16 degrees Celsius) for winter conditions.

The emergency system consists of one or more large fans and ductwork that is sized for heat loads when the diesel generator is in operation. Filters are not usually used on emergency ventilation systems because they could be become loaded and restrict airflow. The system supplies 100 percent outside air with no recirculation. Inside design temperature is 104 to 110 degrees Fahrenheit (40 to 43 degrees Celsius) for summer conditions and 60 degrees Fahrenheit (16 degrees Celsius) for winter conditions.

The outside air exits the building via gravity relief dampers for both the normal and emergency modes of operation. These dampers are nuclear-safety-related.

Fire Protection Considerations

Halon is frequently employed as a fire suppressant in the fire protection system for the Diesel Generator Building. Therefore, there is a need to carefully coordinate the design of the ventilation and fire protection systems. The ventilation system requires additional, low-leakage dampers to isolate all ventilation system openings in the Diesel Generator Building so that the halon does not leak from the building when the system is activated. Controls must be provided to shut down the ventilation system if the fire protection system activates, and to reactivate the ventilation system for purging of smoke after the fire has been extinguished.

2.4.10 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT RADIOACTIVE WASTE AREA SYSTEMS

The plant Radioactive Waste Area processes all of the radioactive waste from plant operations. Ventilation and air cleaning systems for these areas have the same design considerations and requirements as the non-nuclear-safety-related systems associated with the Auxiliary Building (see Section 2.4.3).

2.4.11 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT BOILING WATER REACTOR OFF-GAS SYSTEMS

In boiling water reactor (BWR) plants, radioactive steam is routed directly to the Turbine/Generator Building, as no steam generator is used in this design. The areas of the Turbine/Generator Building are enclosed and are provided with an air cleaning system to ensure any leakage is filtered before release to the environment. The air cleaning system consists of a prefilter, HEPA filter, adsorber, and either a downstream HEPA filter or other high-efficiency filter. The system uses 100 percent outside air for ventilation and, therefore, no recirculation.

In some instances, the off-gas is pressurized, requiring the use of a pressure vessel, pipe, valves, etc., instead of ductwork to ensure pressure boundary integrity.

2.4.12 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT TECHNICAL SUPPORT AREA SYSTEMS

The Technical Support Area of the plant is dedicated for use by the plant staff during plant events or when training for plant events. This area has air conditioning and cleaning requirements that closely parallel the Control Room. The area is required to be pressurized to prevent infiltration. An air cleaning system that meets all of the requirements of Regulatory Guide 1.140[49] is required, including emergency power. <u>However, the system is not nuclear-safety-related, and does not require redundancy</u>. Therefore, one air conditioning unit and one air cleaning unit satisfy the requirements for this area.

Considerations and requirements that apply to the Control Room, (e.g., fire, smoke, chemical exposure, outside air intakes, radiation dose limitations, provisions for air cleanup, testing, and maintenance) are also required for the Technical Support Area.

2.4.13 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT CONTAINMENT AIR ADDITIONS AND RELEASE SYSTEMS

Another unique requirement of ice condenser plants is that they use a low-pressure containment design (15 psig). As a result, the containment pressure during a cold start [60 degrees Fahrenheit (16 degrees Celsius)] and the consequential rise to a normal temperature to 120 degrees Fahrenheit (49 degrees Celsius) can increase the containment pressure to more than the 3 psig set-point that actuates containment isolation and safety system actuation. The reverse also can occur. That is, when the reactor is being shut down, the temperature inside containment can decrease from 120 to 60 degrees Fahrenheit (49 to 16 degrees Celsius), and the resulting pressure decrease can produce a negative pressure inside containment. To eliminate these pressure fluctuations and resulting potential control interactions, an air cleaning system is provided to add make-up air or remove excess air from the containment, thereby controlling the containment pressure.

Due to the pressures involved, the air cleaning system in these plants is comprised of a pressure vessel that normally contains a HEPA filter, adsorber, and downstream HEPA filter so that air can flow both ways in the vessel for either air addition or release from the containment. The pressure vessel is connected to the containment with pipe and containment isolation valves. From the vessel to the unit vent stack, piping is used. Valves, instead of dampers, provide isolation and flow control.

2.4.14 AIR CLEANING SYSTEM DESIGN CONSIDERATIONS FOR COMMERCIAL NUCLEAR POWER PLANT EMERGENCY COOLING SYSTEMS

For nuclear power plants, emergency cooling systems supply an assured source of chilled water to the air handling equipment that serves the control rooms, cable spreading rooms, battery rooms, emergency switchgear rooms, emergency motor control center rooms, penetration rooms, and other rooms within the control complex. These systems are nuclear-safety-related, 100 percent redundant and require separation.

Two types of cooling systems are currently employed for these systems. Centrifugal water chillers are one type. Reciprocating water-chilling equipment is a second. In either case, water for condensing the refrigerant is supplied from the plant's emergency raw water cooling system, which is a nuclear-safety-related system and meets the requirements of ASME Section III, Class 3[50] and ASME AG-1, Section RA.[30] Therefore, the condensers for these systems must be built to these same requirements. Care must be exercised in the control of the flow of this condenser water, as the temperature can vary between 95+ and 35 degrees Fahrenheit (35+ and 1.7 degrees Celsius). Low condenser water temperature can cause an internal pressure reversal in the water chillers that can render them inoperable. Consultation with the water chiller manufacturer is essential to ensure that proper flow and pressure controls are provided to prevent this from occurring. In addition, condensers must be sized to ensure they can produce the required emergency cooling load when the plant's emergency raw water cooling system is switched to the ultimate heat sink (such as a standby nuclear service water pond).

The refrigerant portion of the water chillers' heat exchangers is constructed to the requirements of ASME Section VIII[62] and ASME AG-1, Section RA.[30] The refrigerant system, including the compressor, valves, interconnecting piping, etc., is constructed to the requirements of ASME AG-1, Section RA.[30]

The chilled water portion of the water chillers' heat exchangers (system piping, valves, pumps and cooling coils for the air handling units) are constructed to the requirements of ASME Section III, Class 3,[50] and ASME AG-1, Sections RA and CA[30] Section CA of ASME AG-1 also contains requirements for other types of conditioning equipment.

2.5 AIR CLEANING SYSTEMS FOR FUEL PROCESSING AND REPROCESSING PLANTS

Air cleaning systems for fuel processing plants rely on multistage HEPA filtration. The airborne radionuclides of primary concern are radioactive particles and aerosols, tritium, carbon-14, krypton-85 and iodine-129. Due to heavy particulate loads and radiation levels, most systems are bag-in/bag-out housings that provide protection during filter change-out. Bag-in/bag-out housings are discussed in Chapter 4. Typical air cleaning systems are shown for horizontal flow (**FIGURE 2.5)** and vertical flow (**FIGURE 2.6)**. Housings must be installed with the filter clamping mechanisms downstream to keep them clean and free of contaminants.

Additional guidance for air cleaning systems for fuel processing and reprocessing can be found in the following references:

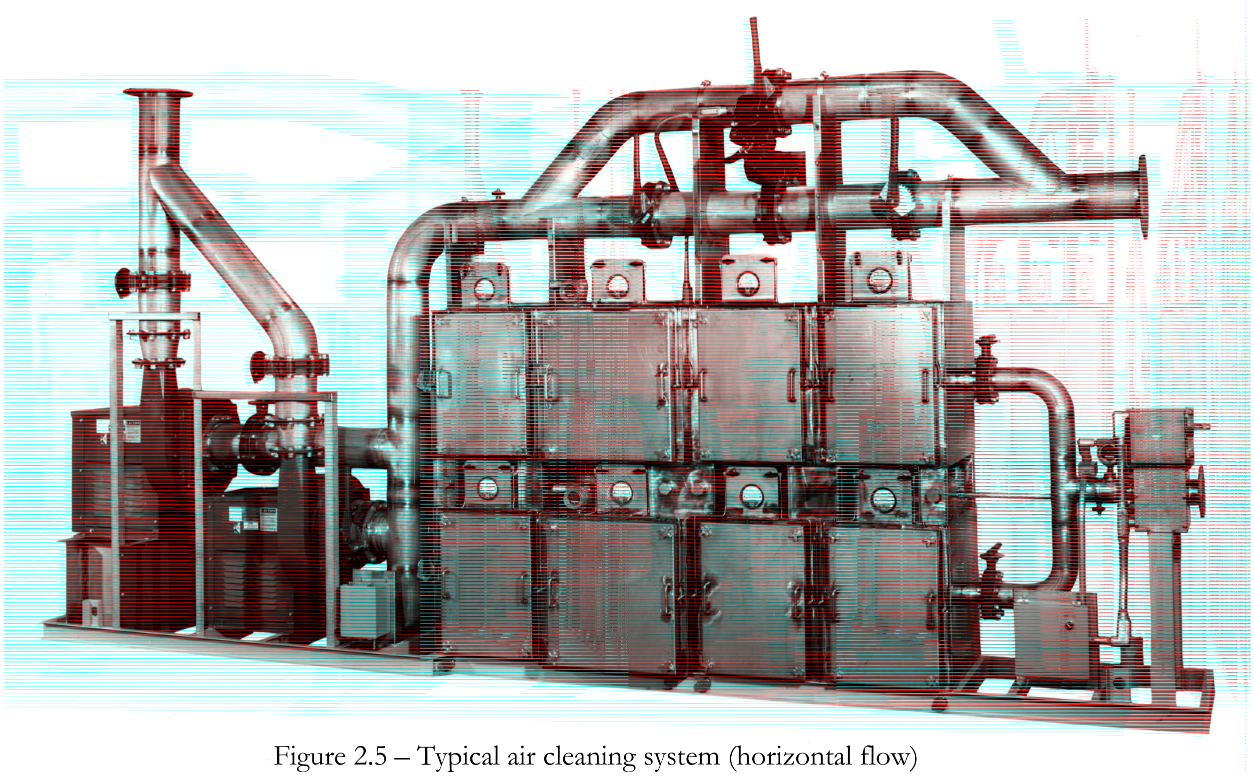

Figure 2.5 – Typical air cleaning system (horizontal flow)